ELECTROOPTICAL MODEL OF THE FIRST RETINA LAYERS OF A VISUAL ANALYZER

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1. Report No. NASA TM-75509	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ELECTROOPTICAL MODEL OF THE FIRST RETINA LAYERS OF A VISUAL ANALYZER		5. Report Date September 1979
		6. Performing Organization Code
7. Author(s) Kh. I. Gaprindashvili, A.D. Riabinin, S.V. Svechnikov, Yu. L. Chibalashvili and A.M. Shkvar		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASw-3199
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546		
		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Optoelektronnaya model' pervykh sloev setchatki zritel'nogo analizatora," Poluprovodnikovaya Tekhnika i Mikroelektronika, No. 8, 1972, pp. 15-21 (A73-13657)

16. Abstract An electrooptical principle of converting and transmitting optical signals is proposed and used as the basis for constructing a model of the upper layers of the retina of the visual analyzer of animals. It is shown that multichannel fibrous optical systems in which the conversion of optical signals is based on the electrooptical principle are optimum for modelling the upper retina layers. The symbolic circuit of the model and its algorithm are discussed.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 14	22. Price

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Visual analyzers of the eyes of animals are compact input devices of biological systems for perceiving images; they support a significant functional load. The interest in modelling of a visual analyzer in animals and its elements is determined, on the one hand, by the problem of creating cybernetic systems for recognizing images and on the other the probability of studying and processing on models of the vision mechanisms.

This article presents a discussion of the principles of constructing an electrooptical model of the first layers of the retina of the eye, the most multielement link of the analyzer.

The retina of the eye of certain invertebrates and all vertebrates contains a group of light sensitive receptors which perceive and transmit light impulses, like a complex fiber optical system [1]. These groups of receptor cells respond at the stage of primary processing of information contained in the images which project them on the optical system of the eye.

The primary processing of information leads to removing excesses in the transmitted signals. An important role in this process of coding is the retina receptor [2]. The functions of the next two layers [3] which contain the nerve cells (bipolar and gangloid) are separation of the simplest characteristics of the image, a selective summation, lateral slowing, suppression of excess of stimuli, separation of the invariant characteristics of the image and transmission of the information to the brain. They are complex in structure and organization of the neuron circuit which consists of polyfunctional

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*Numbers in the margin indicate pagination in the foreign text.

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elements which form, at different levels of the retina, a system of receptor fields [4].

An analysis of the structure, topology and principles of the operation of visual analyzers in animals [5, 6] and also the possibilities of fiber optics [3] which have been developed in the last decade, make it possible to conclude that optimum modelling of the first layers of the retina corresponds to multichannel fiber optical systems in which the output conversion of optical signals is accomplished on the basis of an electrooptical principle [7]. Here, high resolution of the receptive fields is achieved, basically a limited resolution of fiber optical elements, high interference protection of the circuits of the multichannel optical communication [8], uniformity of conversion of the signals at each of the processing stages, the possibility of obtaining optical and electrical signals which are uniform in type and a high degree of minimization of the solution.

These advantages are absent in the known electronic models of visual analyzers of different types [9--12], whose interference protection and reliability change sharply with an increase in the number of elements and the communication among them [13].
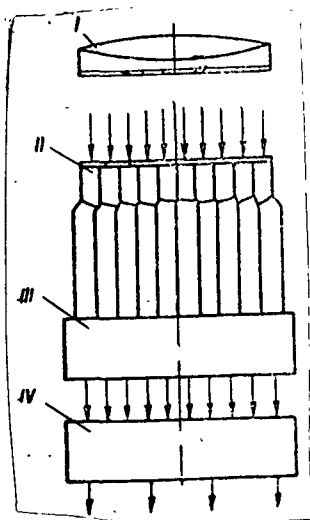
The creation of an electrooptical model of the first layers of the retina of a visual analyzer which provides a system of input and subsequent processing of the information of the technical analog of the visual analyzer [14] includes development of a functional system of the model, its fiber optical and electrooptical components.

A Functional Diagram of a Model and the Principle of Organization of /16 Receptive Fields

For studying the phenomenon of perceiving images it is necessary to have a model of the first layers of the retina, according to functional properties close to the biological prototype. Here, it is not necessary to add a high degree of authenticity to the mechanisms of the secondary processing of information, but the coding mechanisms which respond to separation of the simplest characteristics which

describe the image must be modelling fairly precisely. These considerations are the basis for developing the functional model diagram.

An electrooptical model of the first layers of the retina [14] is presented in Figure 1.

The input block for admission and coding of visual information is a fiber optical converter consisting of an intake screen made in the form of a polished (on the side of the image input) matrix tightly packed and sintered optical fibers smoothly passing into a system of flexible bundle-like guides. Each bundle is in optical contact with the photoreceivers of the block for separating the primary characteristics of the image.

To classifier

Figure 1. A block diagram of an electrooptical model of the first layers of the retina of a visual analyzer:

I--optical system for projecting the images; II--input block for admitting and coding images (fiber optical converter); III, IV--blocks for isolating the primary and invariant characteristics of the image, respectively.

The block for isolating the primary characteristics and the block for isolating the invariant characteristics of the image consist of several panels in contact with each other on which electrooptical converters are placed with lines, thresholds and logarithmic characteristics. The connection between the panels and the blocks for processing information are made using fiber optical components which are a combination of flexible light fiber bundles, rods, phokons and so forth.

The system adopted for processing the information corresponds to the principle of organization of receptor fields of the retina of biological visual analyzers of vertebrates. An example of such an organization can be the eye of a frog which has its own electronic analog [11].

It is well known [15] that in bionic modelling, the shape of a

separate receptive field can be selected at random. In accordance with this, in Figure 2, one sees diagrammatically a small part of a fiber optical converter and its connection with the electrooptical converters of the first layers of the retina model. For convenience in considering organization analogs of receptive fields in the system, only seven (1--7) groups are included each of which is in optical contact with the block for isolating primary characteristics of the image III. These seven groups of light guides form elementary receptive fields of the model of the first layers of the retina. They overlap each other; due to this each group of light guides participates in the formation of the seven receptive fields as a central zone in one field and as an element of the peripheral zone in each of the six overlapping adjoining fields.

As is shown in Figure 2, in the block for isolating primary characteristics of the image, the light guides with their ends which are free lead to the stimulating and slowing input of neurolike electrooptical converters with /17

Figure 2. Diagram of a section of a fiber optical converter and its connection with the electrooptical converter of the first layers of a retina model.

logarithmic characteristics designated by the numbers 8--12. Element 8 has only a stimulus connection and forms the B-field. Element 9 is stimulated from the bundle of light guides from groups 2, 3 and 4 and

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is slowed down by the light flux from groups 5, 6 and 7. It models
the BT-field. Element 10 has the opposite character of communication
as compared with element 9, that is, it models the TB-field. The
analog of the TBT-field is represented by element 11. It is excited
by central group 1 and is slowed down by groups 2--7. Inverse
element 11 has the same type of connection as element 12 which models
the BTB-field. Now if the function of brightness of the image
created by optical system 1 on the input matrix of block II is
approximated by the power polynomial of type

$$B(x, y) = \sum_{i, j=0}^{n} a_{ij} x^i y^j,$$

(1)

then at the output of elements 8--12 there will be optical signals
proportional to the coefficient of this polynomial: a_{00}, $-a_{10}$, $+a_{10}$,
$-a_{22}$ and $+a_{22}$, respectively. Then, relationships of the type

/18

(2)

$$
\begin{array}{|lll|}
\hline
+ b_{10} = \dfrac{+ a_{10}}{a_{00}}; & - b_{10} = \dfrac{- a_{10}}{a_{00}}; & + b_{31} = \dfrac{- a_{22}}{- a_{10}}; \\
- b_{21} = \dfrac{+ a_{12}}{- a_{10}}; & - b_{22} = \dfrac{- a_{22}}{+ a_{10}}; & + b_{22} = \dfrac{+ a_{22}}{+ a_{10}} \\
\hline
\end{array}
$$

are not dependent on illumination of those objects whose images are
being analyzed in the model of the first layers of the retina.

Because the electrooptical elements 8--12 at the output have
electrical signals proportional to $\log a_{00}$, $\log|-a_{10}|$, $\log|+a_{10}|$, $\log|-a_{22}|$
and $\log|+a_{22}|$, the coefficients of b_{lk} can be calculated in logarithmic
scale in the following way:

$$\log b_{lk} = \log \frac{a_l}{a_k} = \log a_l - \log a_k.$$

(3)

The operations of adding or calculating signals from the outputs of
elements 8--12 are done on electrooptical neurolike elements with
linear characteristics (with forward and reverse conversion of light

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energy to electrical and the reverse).

From relationships (1)--(3), it follows that the values determined as

$$\log C_{lk} = \log \frac{b_{lk}}{b_{l-1,\,k-1}} = \log b_{lk} - \log b_{l-1,\,k-1},$$ (4)

are invariants of relatively large scale elements of images.

All of the uniform operations of calculation described above are made on elements 13--26 of the model, whose output signals correspond to the primary characteristic of the images formed by block III, and are the initial values for calculating integral characteristics.

Block IV of the model isolates, from the primary characteristics, integral characteristics which do not depend on shifting of the image along the artificial retina, changes in dimensions of the images and their rotation. Here, the electrooptical converter 27 adds up the signals of $\log b_{10}$ calculated for each group of fibers for the entire field of the retina. Elements 28--32 fulfill an operation in the form

$$L_r = \sum_{i=1}^{n} \log b_{ir},$$ (5)

where n--is the number of groups of bundlelike waves which form the matrix of the input and coding block; i--is the number of groups; L_r--is the value of the signal at the input of the electrooptical converter for the r-image. The value of L_r determined in such a way is invariant for conversion of large scales along the three axes which project the image on the retina (x,y--spatial coordinates and z--illumination).

As a result of adding (5) at the outputs of block IV with channels 47--52, invatiant characteristics of the image will be obtained.

In block IV, the 8 remaining (out of 14) signals are introduced corresponding to each receptive field (channels 33--40) and the proportional values--$\log C_1$; $+\log C_1$; $+\log C'_2$; $-\log C'_2$; $+\log C''_2$; $-\log C''_2$; $-\log C''_2$; $+\log C''_2{}'$, respectively.

From an analysis of the spatial function of output signals (for /19 example, the type $-\log C_1$) it follows that changes in dimensions of the image function do not change the shape and value at the extreme points but are contracted or elongated. Having measured the total extreme values of this function and their difference, one can obtain characteristics which are invariant to conversion of scale, transmission of the image and change in illumination. These operations are realized by an electrooptical structure with fiber optical connections (Figure 2, bottom left). The principle of operation of this structure includes the following: signals from channel 33 are fed to electrooptical converter designated as $33_{(i)}$ (where i = 1, 2, 3 and so forth) connected in turn to 2 underlying layers and also with layers 53 and 54 which makes it possible to obtain output signals after layer 53 corresponding to the value of the functions of $-\log C_{1i}$ in its minimums and after layer 54--in its maximums. The summation of these values on the electrooptical elements with linear characteristics (55 and 56, respectively) and with different weights on their outputs (59 and 62, respectively) makes it possible to measure the total and the extreme values of the function of primary characteristics of the image. On elements 57 and 58, the difference between the totals of the values of the functions at the points of minimums and maximums is measured. This difference is taken out of block IV along channel 60 and 61. The initial data then is formed on the output channels 34--40 and is introduced into the appropriate channels of block IV.

Thus, the output electrical signals 47--52 and the eight groups 59--62 are invariant for each class of images undergoing analysis.

The output signals of the model formed in this way of the first layers of the retina are introduced directly into the classifying device (neuron solving circuit, digital computer, etc.).

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Components of Fiber Optics

The components of fiber optics used in the model can be divided into complex systems, elements of communication and parts for secondary use.

The fiber optical converter (Figure 3) and the system for totalling the light pulses (Figure 4) belong to the complex fiber optical system.
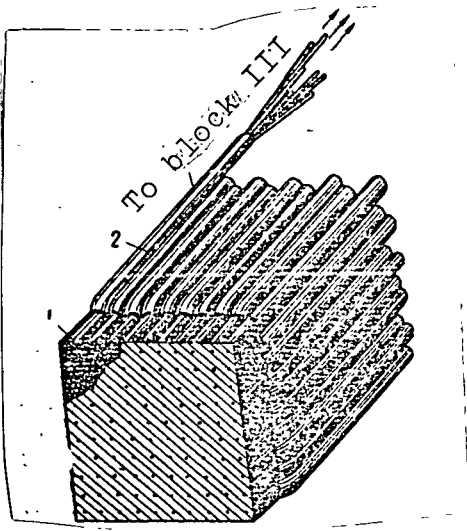

Figure 3. The main design of the fiber optical converter:

1--input matrix;
2--system of flexible light guides

The structure of the fiber optical converter (Figure 3) provides continuous transfer from the matrix of the input (admission screen) to the propagation system which is characterized by a high coefficient of splitting [15]. The light guides of the fiber optical converter which transmit optical signals lead to the panel with through apertures on which they optically are in contact with light sensitive elements of the block for isolation of the simplest features of the image.

The main device of the system for adding the light impulses is shown in Figure 4. It consists of a certain number of flexible thin light guides leading at one end to the electrical luminescent light source and at the other end are collected in a bundle which optically contact the base of the converging

Adding of the optical signals is done by photoreceiver 4 placed on the converging end of the phokon.

The flexible and rigid cylindrical and conical light guides designed for transmitting light signals along the optical communication channel and the communication elements. They can be made
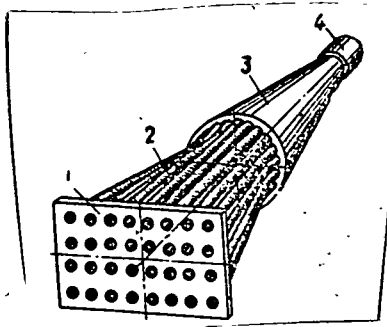
Figure 4. A system of totalling flight pulses:

1--matrix of electro-luminescent sources of light; 2--bundle light guides; 3-- convergent phokon; 4--photoreceiver
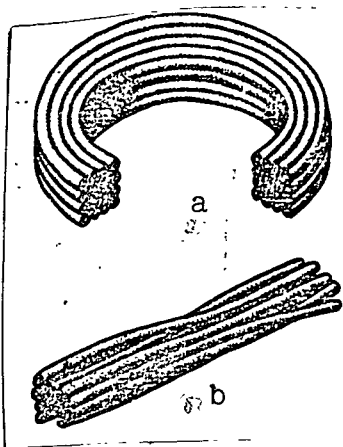

Figure 5. Fiber optical bundle light guides:

a--with coherent; b--with noncoherent fiber inserts.

in the form of coherent (Figure 5a) and noncoherent (Figure 5b) bundles of fibers with diameter from 5 to 100 μm which pro-vides high flexibility of the bundle [16] The rigid light guides can have practically any shape imparted to them during manu-facture. Also the development of film light guides in electrooptical devices is well known [17]. Here, there is a possi-bility of making electrooptical layouts in the form of integral thin film systems including multilayer which must essentially change the topology and overall dimensions of models similar to the one considered.

The matrix surface plates manufactured in- the shape of discs and intended for measuring the frequency contrast characteris-tics which determine the transmission properties of the admission screen of the input block and coding of visual information are part of the auxiliary fiber optical parts. Manu-facture of all the fiber optical components listed above out of optical fibers with high transmission for the visible field and satis-factory for that close to the infrared field, at the present time, does not have any par-ticular difficulties [16].

Conclusion

The model proposed of the first layers of the eye retina is realized by a number of biological mechanisms for processing infor-mation and contains structural correlates of neuron analyzing net-works such as different types of receptive fields, neuronlike elements made on electrooptical converters with forward and reverse

conversion of light energy to electrical, horizontal addition and others.

The use of an image analyzer according to the system proposed, which can be made on electrooptical converters with fiber optical connections, makes it possible to analyze images with very small dimensions, to simplify the structure of the neuron resolution networks or the algorithms of the solution adopted for classifying   /21 images when putting them into a TsVM [Tsifrovaya vychislitel'naya, mashina, digital computer]. The structure described can be realized using new structural elements thanks to the fact that the system solution proposed is based on fully determined principles and does not require any adjustment.

This device makes it possible:

to analyze information on images with high resolution capability which significantly exceeds the resolution capability of the electronic models;

to compact information with a huge number of fibers of the intake block I up to 16 output channels, based on principles which have not been used in the electronic models known up until the present.

to provide independence of signals in the channels from the change in scale of the images, their rotation and transition to the input surface plate.

It has the following system technical qualities: reliability, interference protection, small dimensions and low energy requirements which, in the final analysis gives it indisputable advantage over other known models when using them in involved functional complexes.

The use of electrooptical and fiber optical components provides complete bypassing of inputs and outputs of separate layers and elements located in these layers which is impossible in electrical

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models of the retina. Here, one could achieve significant ampli-
fication when transmitting signals which also is a necessary con-
dition of organizing multilayer structures. Moreover, it is very
important that when using the components proposed in this model it
is possible to achieve a good quality of linear summation of optical
signals at the inputs of the electrooptical elements and also a
high degree of similarity in dual conversion of energy characteristic
for biological structures. As a result of the dual conversion it
is possible to achieve flexibility of the model because it is
possible to use not only optical but also electrical signals of
the electrooptical systems.

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